DCS cloud comparison between MODIS/GOES and ARM surface-aircraft measurements during MC3E at ARM SGP

Xiqual Dong

Baike Xi, Jingjing Tian, and Jingyu Wang

University of North Dakota

Pat Minnis, Sunny Sun-Mack, Mandy Khaiyer

NASA LaRC

ARM observations/retrievals during MC3E

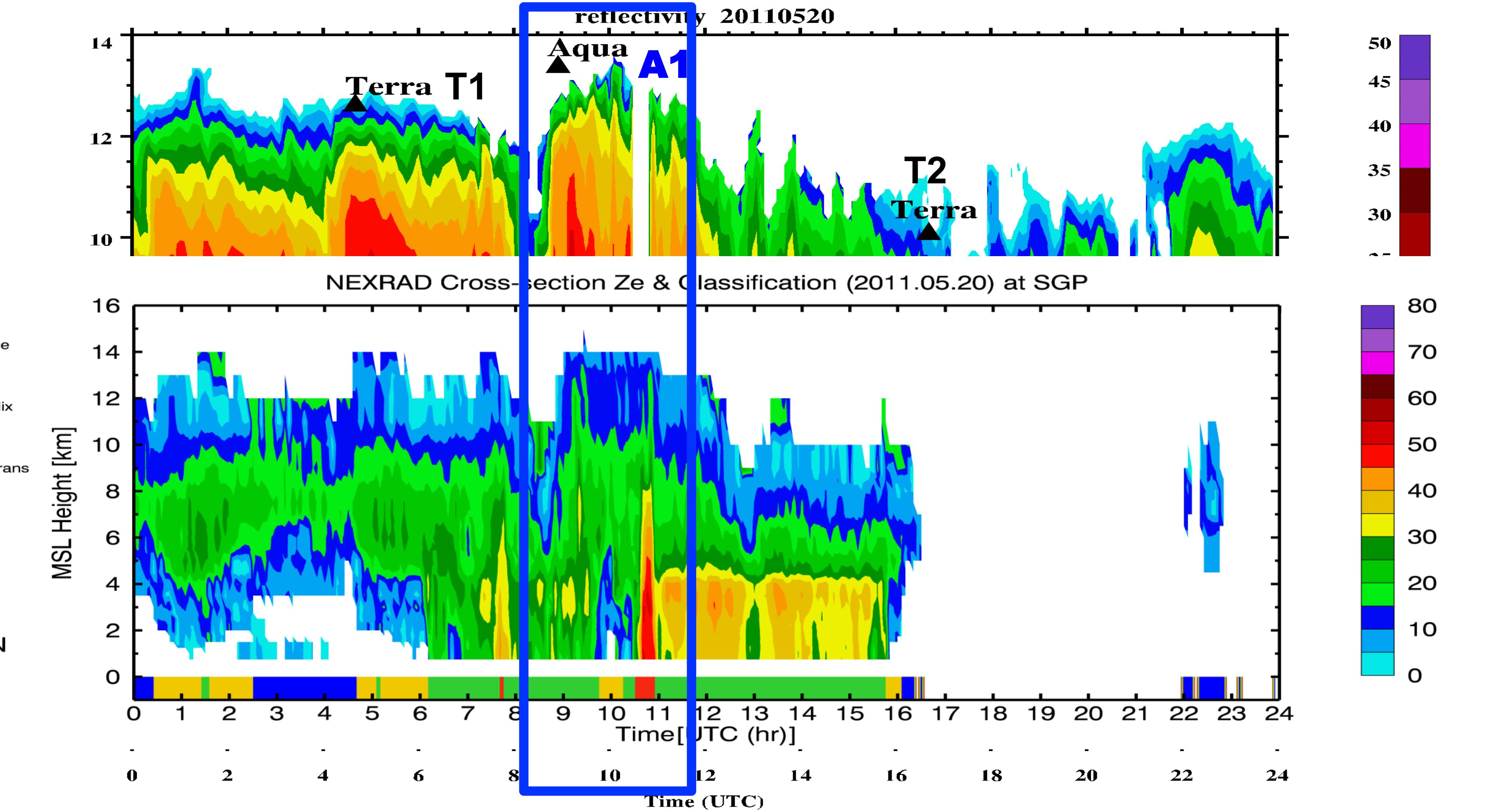
- **Cloud top height: KAZR radar at DOE ARM SGP site;**
- **Particle size: using newly developed retrieval algorithms**

***Method 1*: retrieved re based on KAZR reflectivity and number concentration measured by UND Citation;**

***Method 2*: retrieved re based on the terminal velocity;**

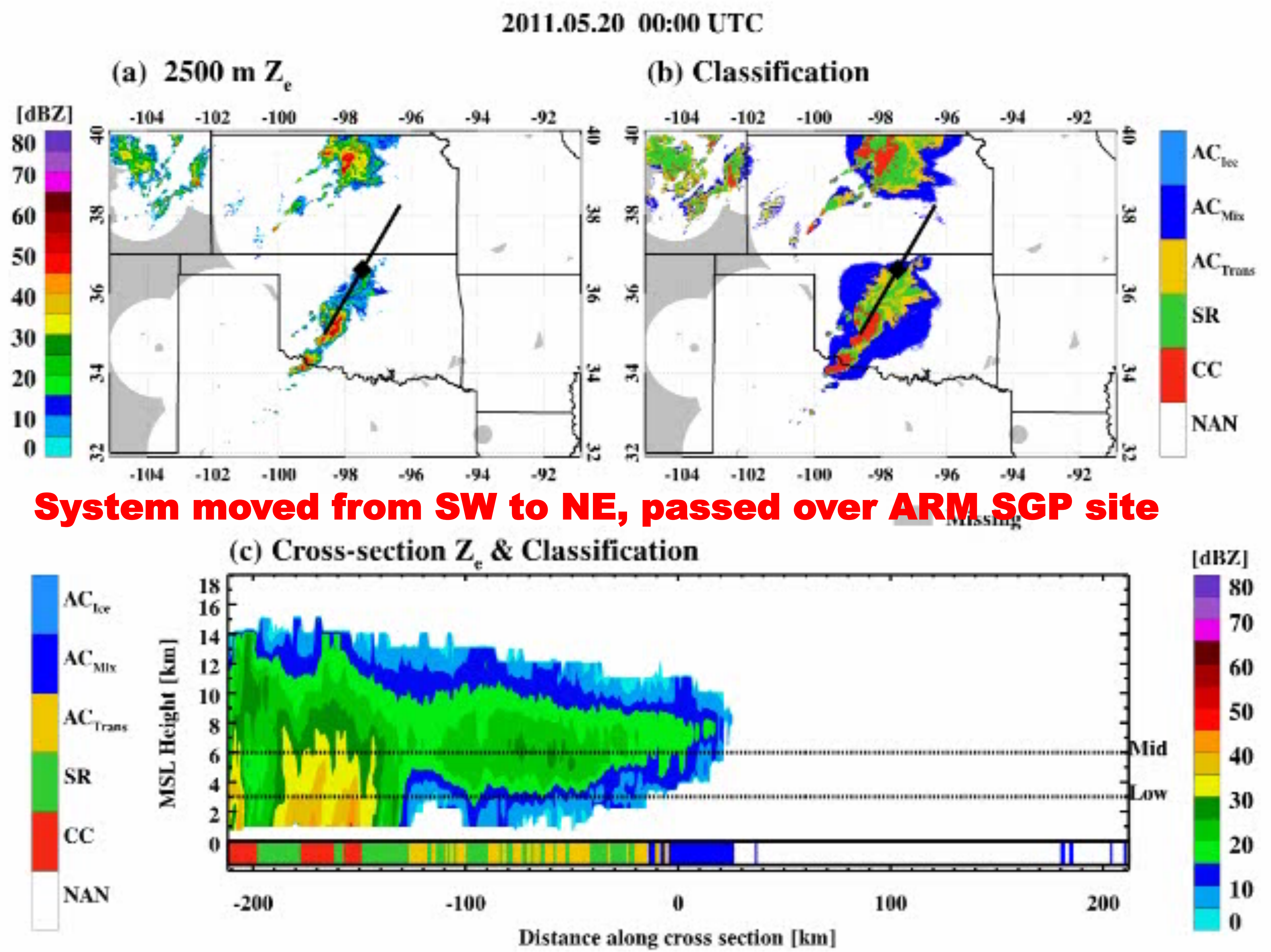
Both are compared with UND aircraft in situ data

Cloud-top height comparison between radars and MODIS/GOES (May 20th, 2011)

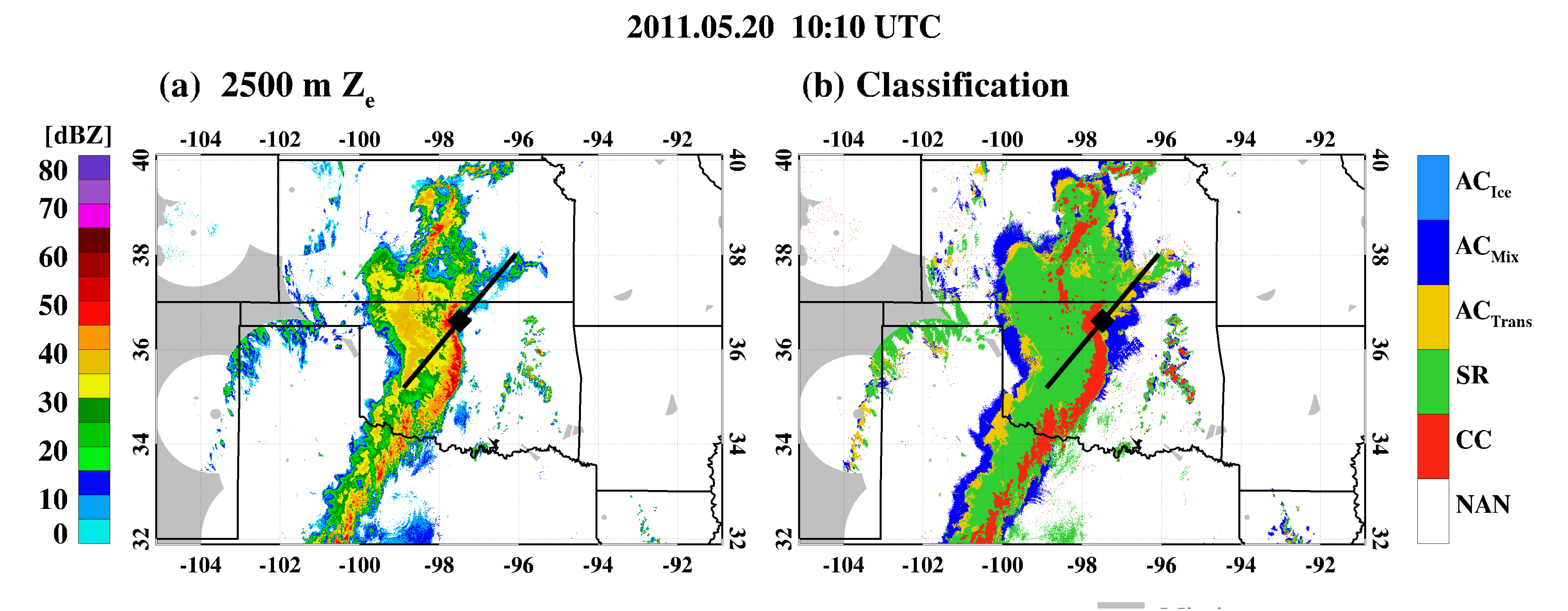


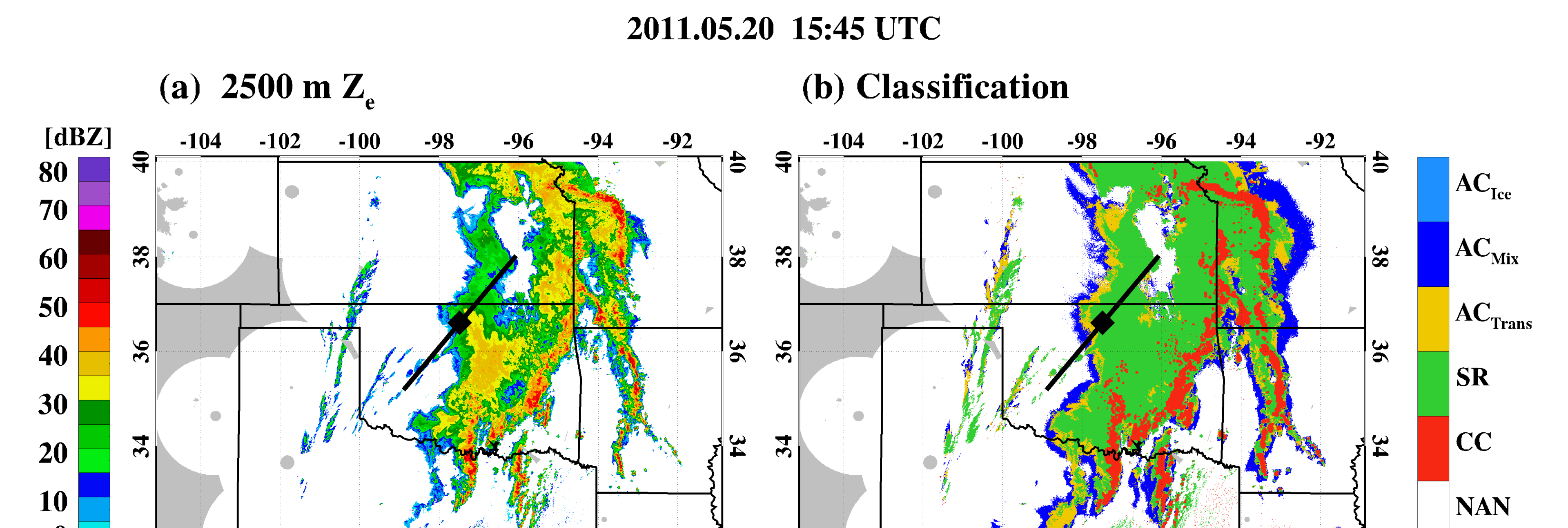
Terra MODIS heights (T1 & T2) agree with radar cloud-top heights; Z_{top} at Aqua overpass (A2) is lower than the radar measured cloud top→ This is reasonable for optically thin clouds.

Z_{top} at A1 is ~ 1 km higher than the radar cloud top because it is surrounded by the convective core and the radar signal might be attenuated by the precipitation, but NEXRAD detected Ztop ~ 14 km.

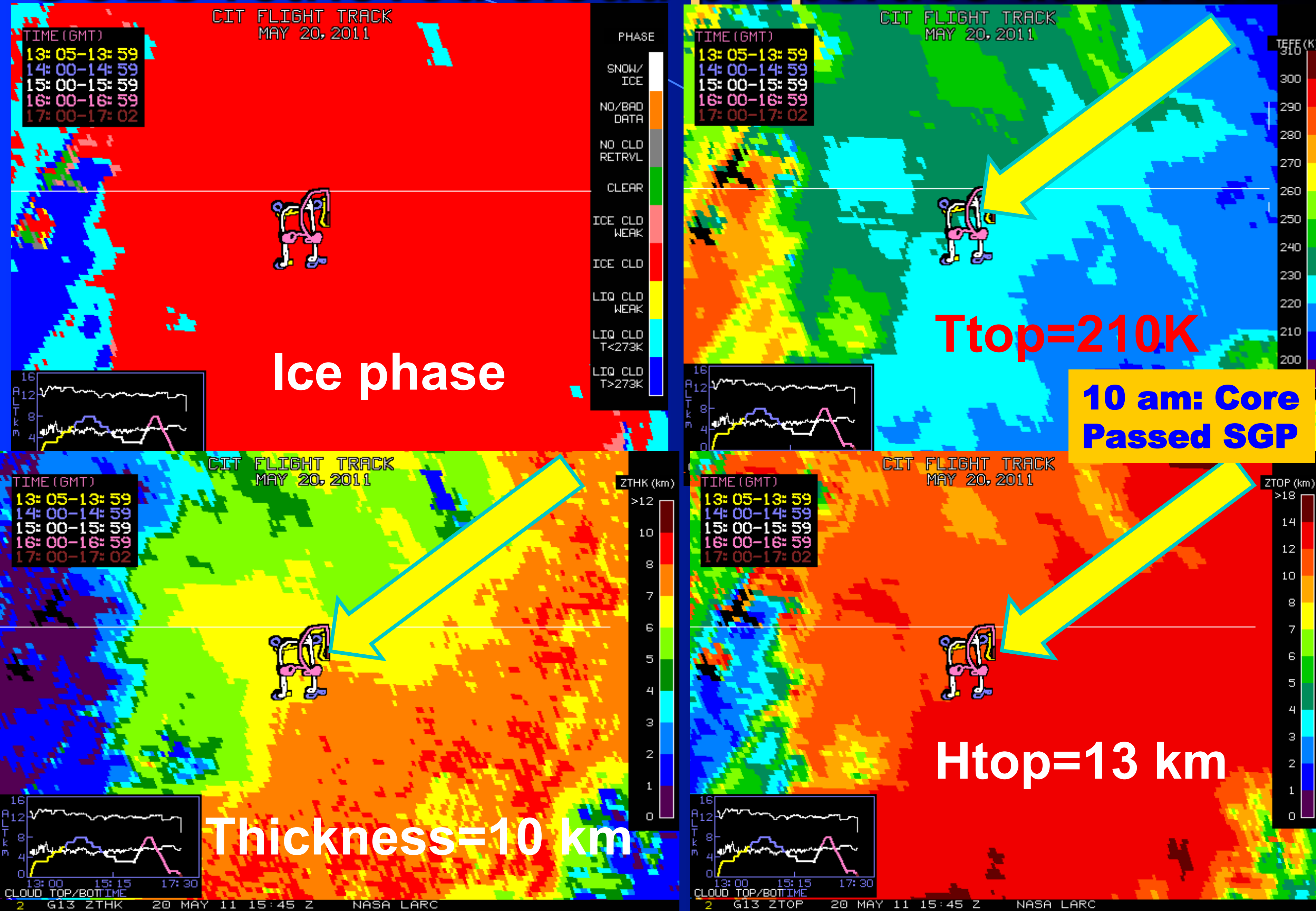


2011.05.20 00:00 UTC
(a) 2500 m Z_e
(b) Classification
[dBZ]
80
70
60
50
40
30
20
10
0
AC_{Ice}
AC_{Mix}
AC_{Trans}
SR
CC
NAN
System moved from SW to NE, passed over ARM SGP site
(c) Cross-section Z_e & Classification
MSL Height [km]
Mid
Low
Distance along cross section [km]


2011.05.20 10:10 UTC
(a) 2500 m Z_e
(b) Classification
[dBZ]
80
70
60
50
40
30
20
10
0
-104
-102
-100
-98
-96
-94
-92
40
38
36
34
32
AC_{Ice}
AC_{Mix}
AC_{Trans}
SR
CC
NAN


2011.05.20 15:45 UTC
(a) 2500 m Z_e
(b) Classification
[dBZ]
80
70
60
50
40
30
20
10
-104
-102
-100
-98
-96
-94
-92
40
38
36
34
AC_{Ice}
AC_{Mix}
AC_{Trans}
SR
CC
NAN

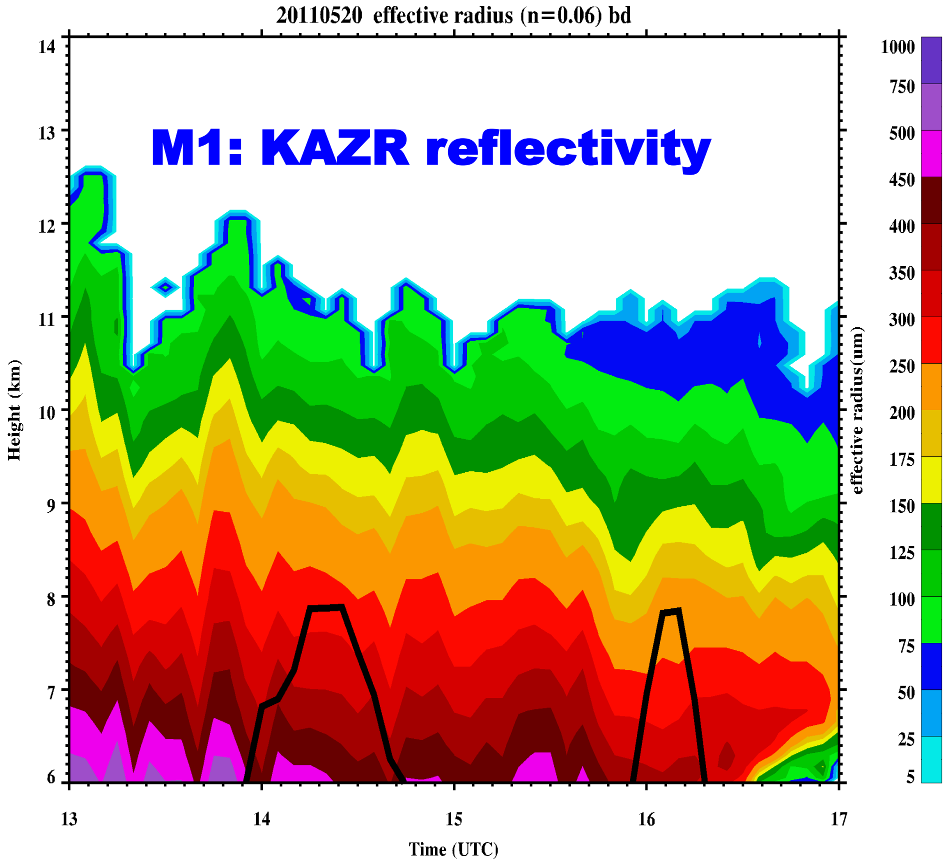
GOES retrieved cloud properties at 15:45Z

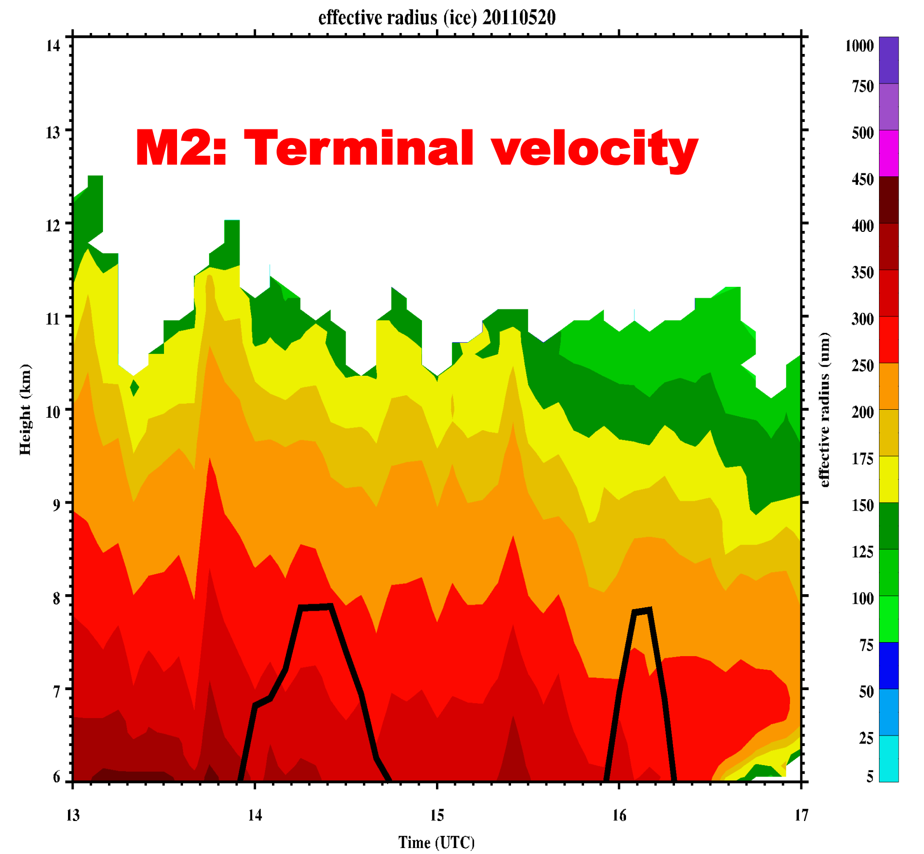


Conclusion:

Both MODIS and GOES retrieved cloud-top heights for DCS are within ARM Cloud and NEXRAD radar observations for this case.

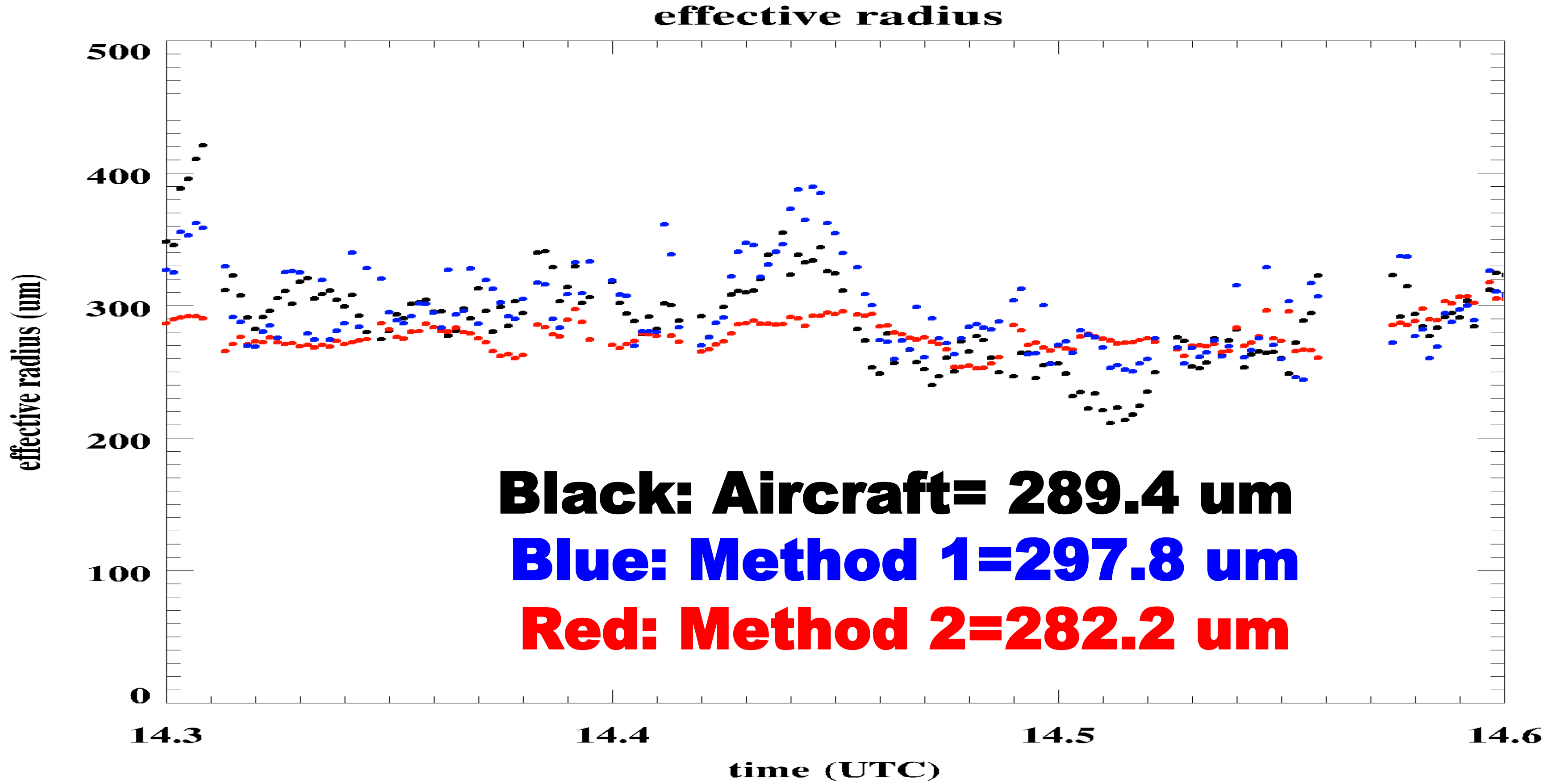
Two new methods are developed to retrieve DCS particle size (re)





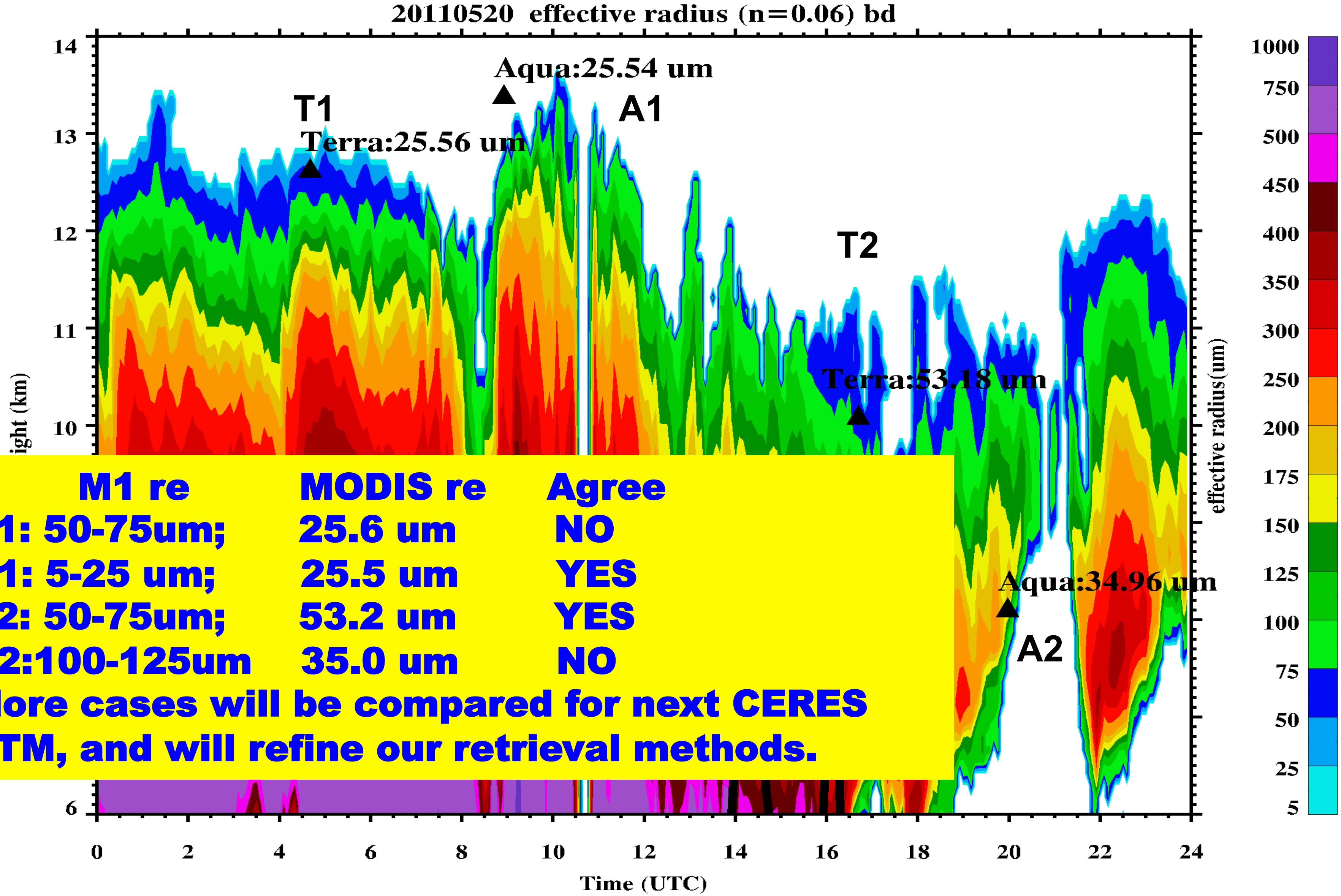
- **Black lines are aircraft flight tracks. The aircraft measurements above 6 km will be used for validating M1 and M2 ice cloud re values.**
- **M1 re values have much finer vertical resolution than those from M2.**
- **M1 re values increase from 50 um at cloud top to 300 um at 7 km, they are about 25-50 um smaller than those from M2 at upper levels.**

Validation of M1 and M2 results using aircraft data



Although their means are close to each other, the correlation of M1 retrieved re with aircraft data is 0.7, while M2 is 0.11.
Both methods need to be further validated by aircraft data with more cases during MC3E IOP.

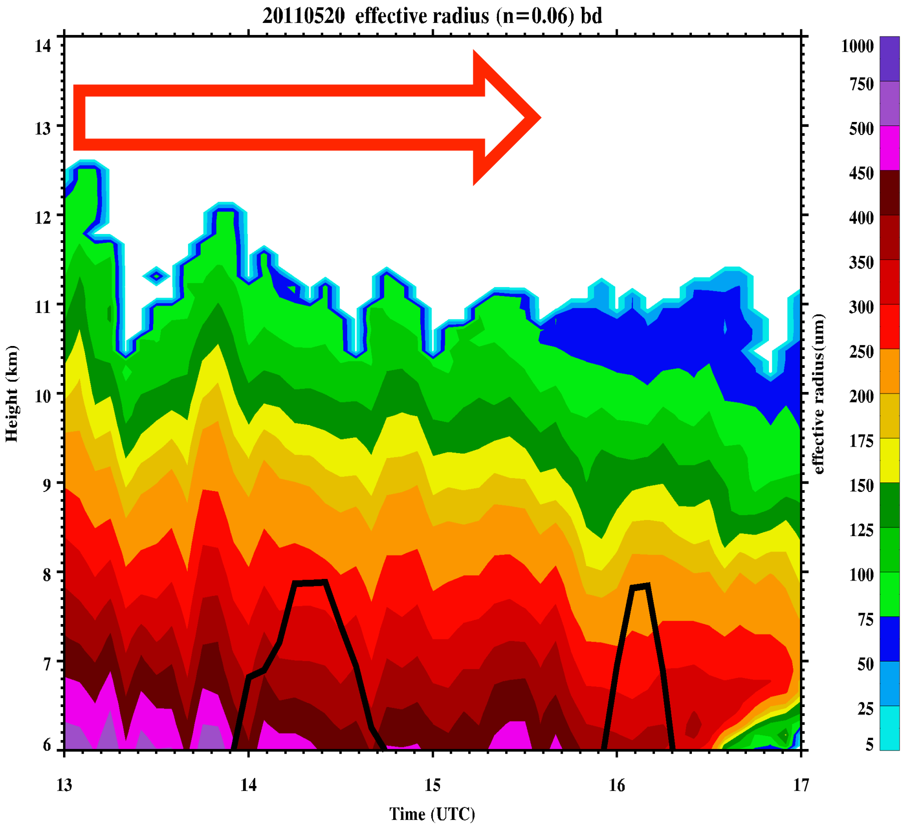
Method 1: Combined KAZR reflectivity with Aircraft measured cloud number concentration

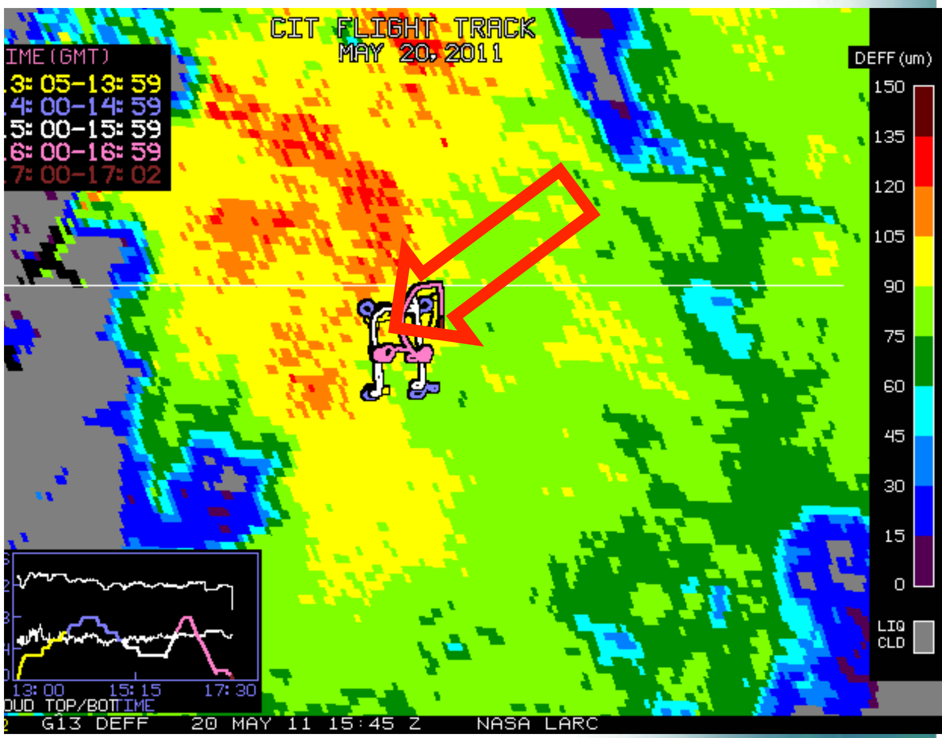


	M1 re	MODIS re	Agree
T1:	50-75um;	25.6 um	NO
A1:	5-25 um;	25.5 um	YES
T2:	50-75um;	53.2 um	YES
A2:	100-125um	35.0 um	NO

More cases will be compared for next CERES STM, and will refine our retrieval methods.

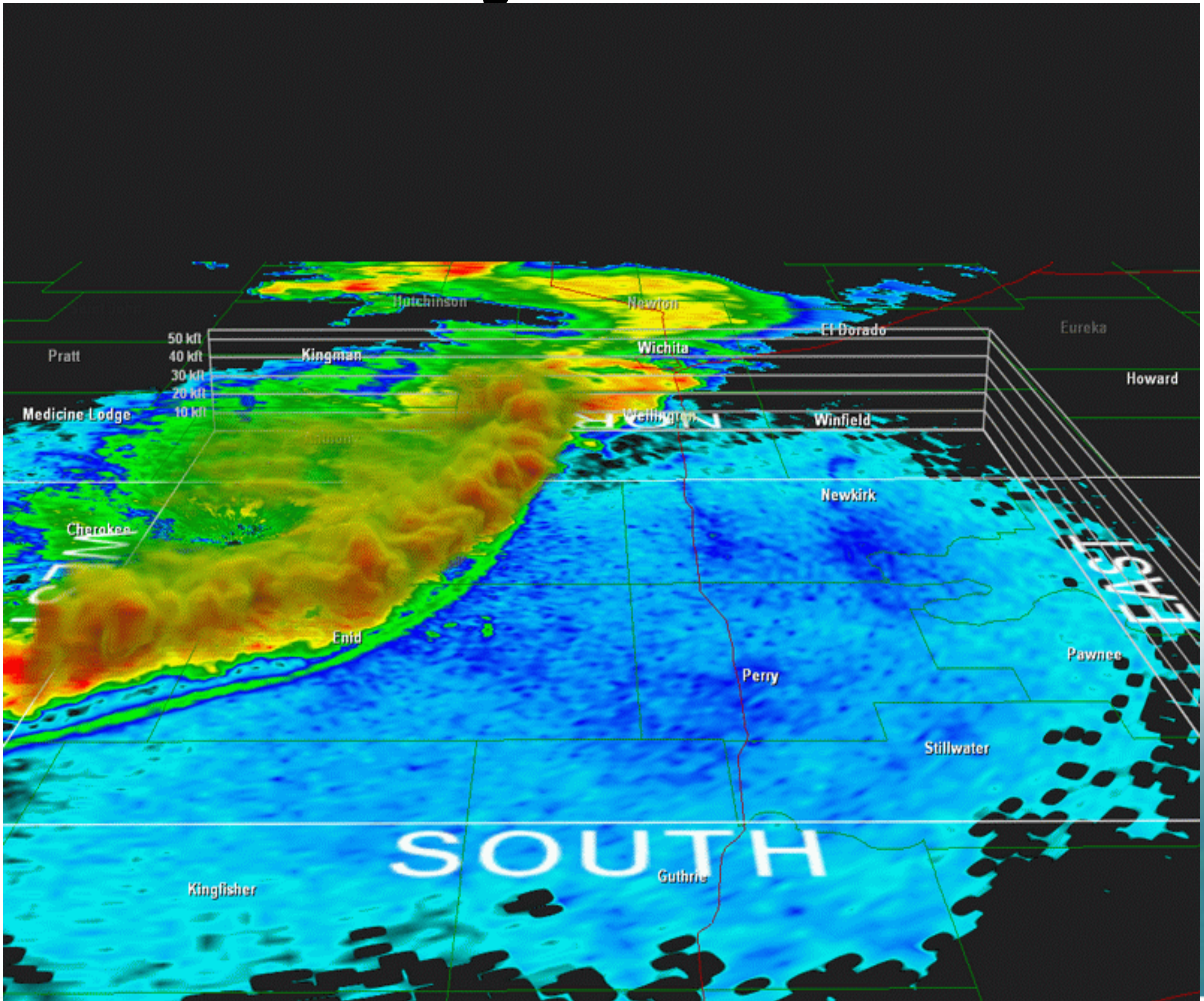
GOES retrieved cloud properties at 15:45Z





ARM re values range from 75-125 um, GOES De values range from 75-120 um.

Thanks for your attention!



Parameterization of Cloud thickness vs cloud LWP and cloud-top temp

Xiquan Dong, Baike Xi, Adam Schwantes
University of North Dakota

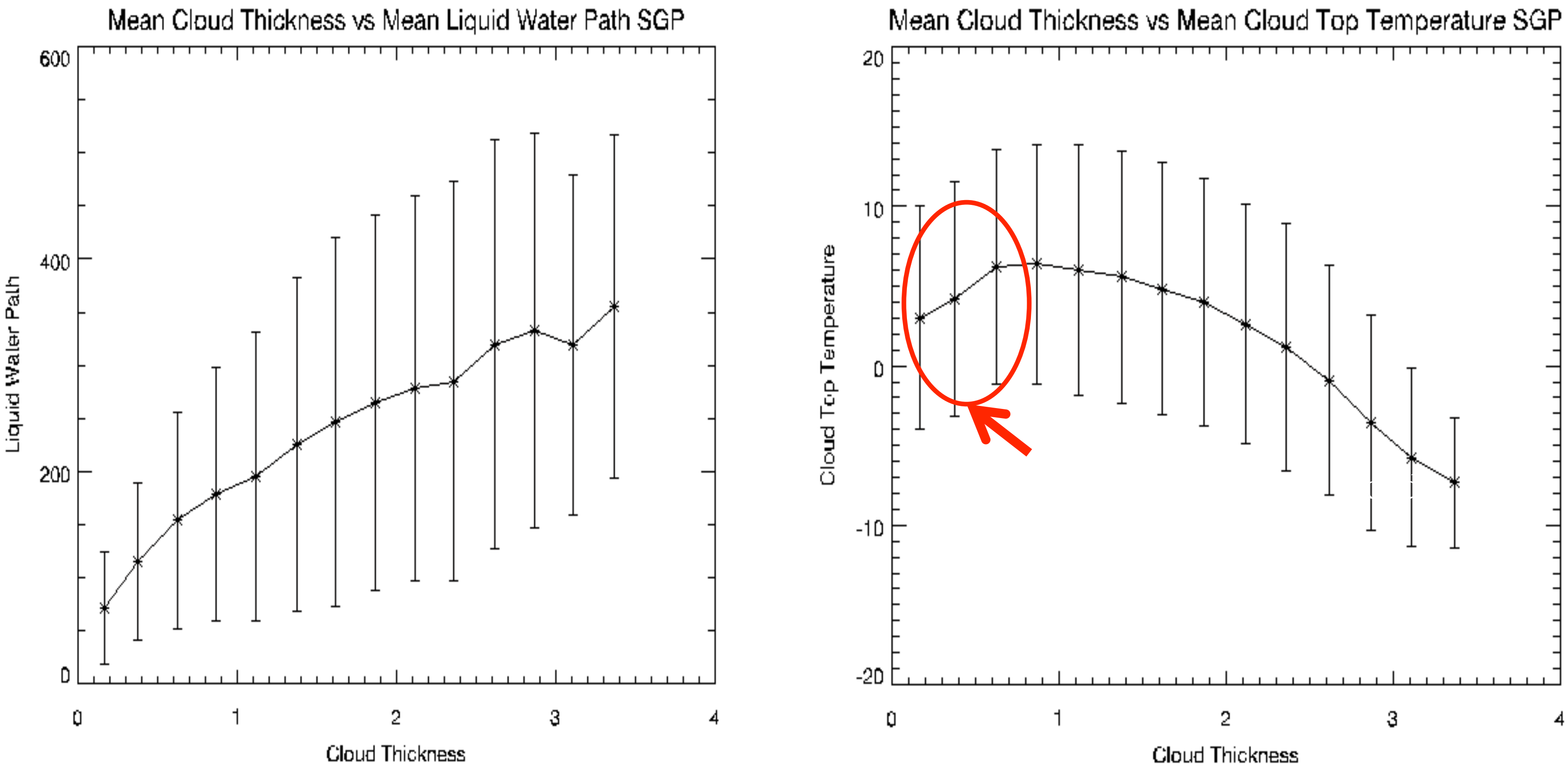
Data

- Data used
  - ARM SGP Site (Oklahoma) 10 years of data (1997-2006)
  - ARM Azores site (Atlantic) 19 months of data (2009-2010)
  - ARM NSA site (Barrow, Alaska) 6 years of data (1999-2004)
    - Only use May-September data for NSA site
- Variables
  - Liquid Water Path
  - Cloud Thickness
  - Cloud Top Temperature

Methods

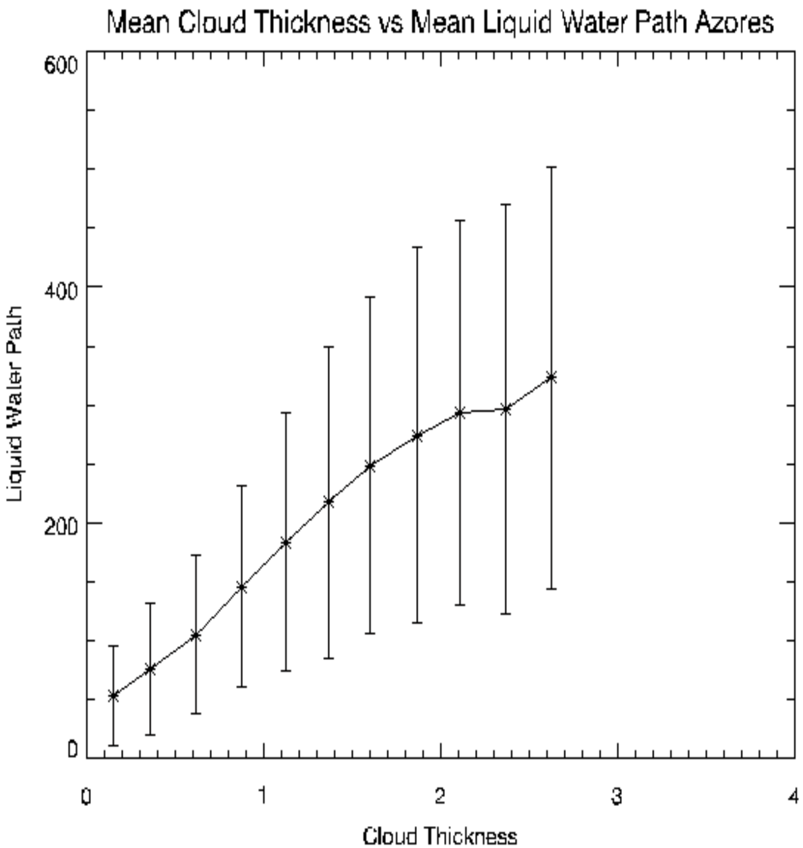
- **Cloud Top Temperature Threshold= 260K+**
- **Low Clouds (Cloud Top Height< 4km)**
- **Removed twilight hours(except NSA site)**
- **Cloud Thickness > 50 m**
- **Liquid Water Path must be between 20 and 700 g/m^2**
- **Bin**
  - **Took average of all values every 250 meters of cloud thickness**
- **Multiple Linear Regression line fit**
- **Statistics**
  - **Multiple linear correlation coefficient (R-Value)**

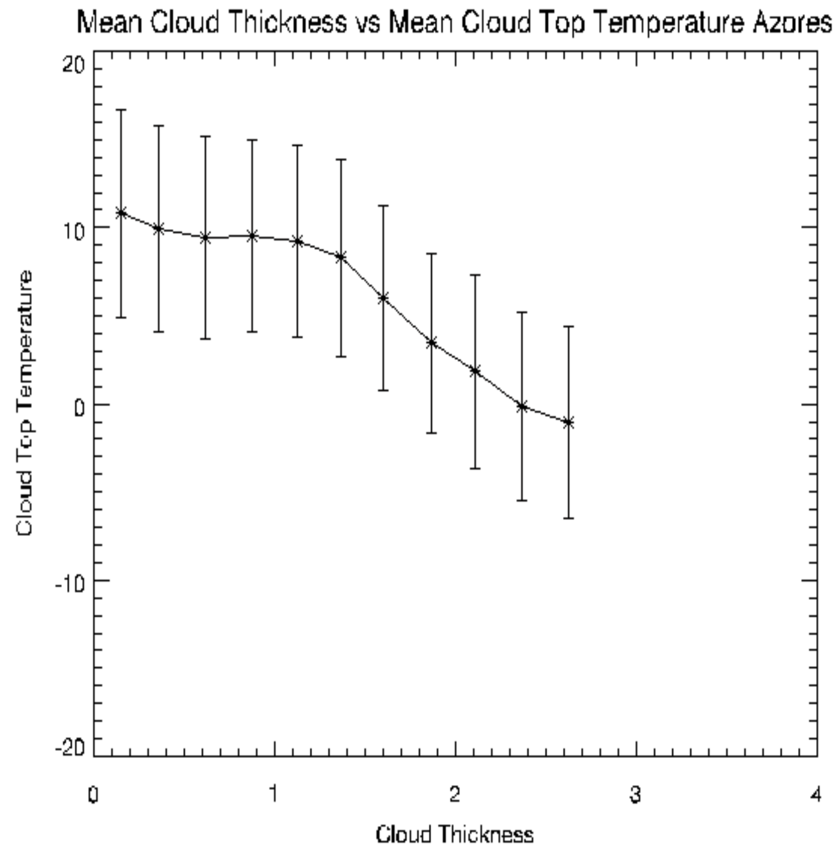
SGP



- $\Delta Z = .0021 * LWP - .004 * (T_{top} - T_0) + .588$
- **R-value=.458**

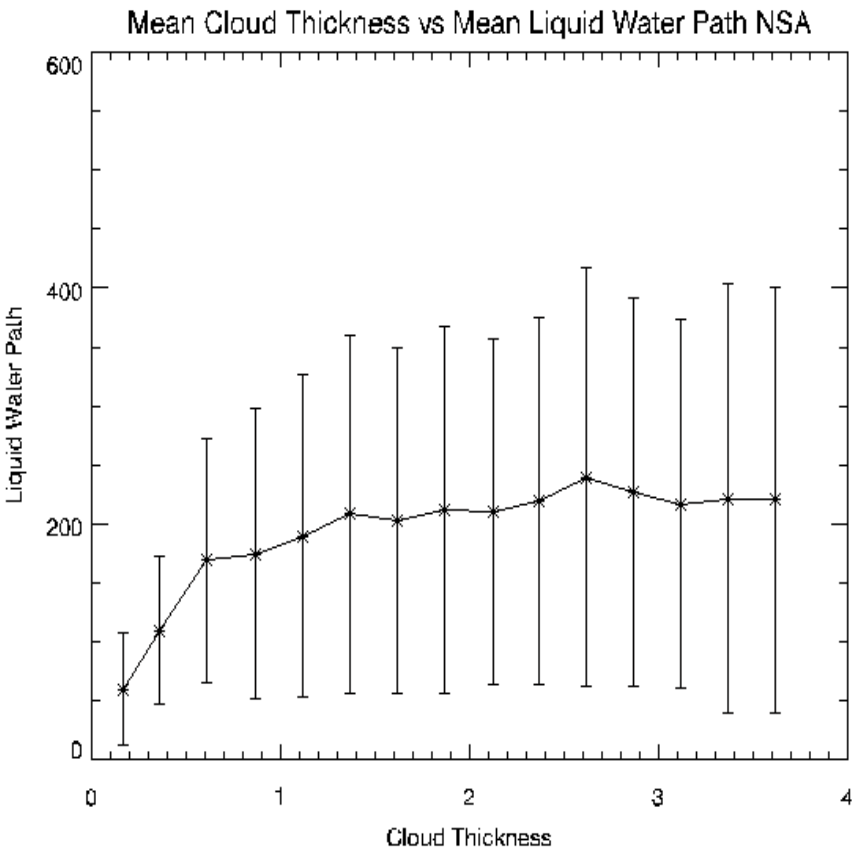
Azores

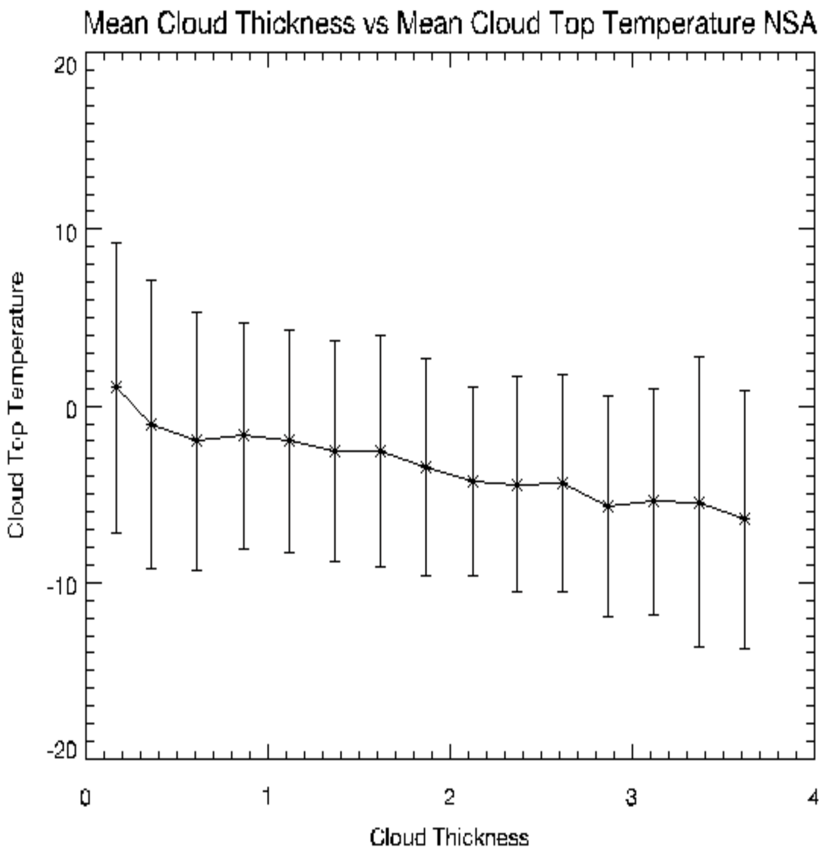




- $\Delta Z = .0029 * LWP - .037 * (T_{top} - T_0) + .784$
- R-value=.72

NSA



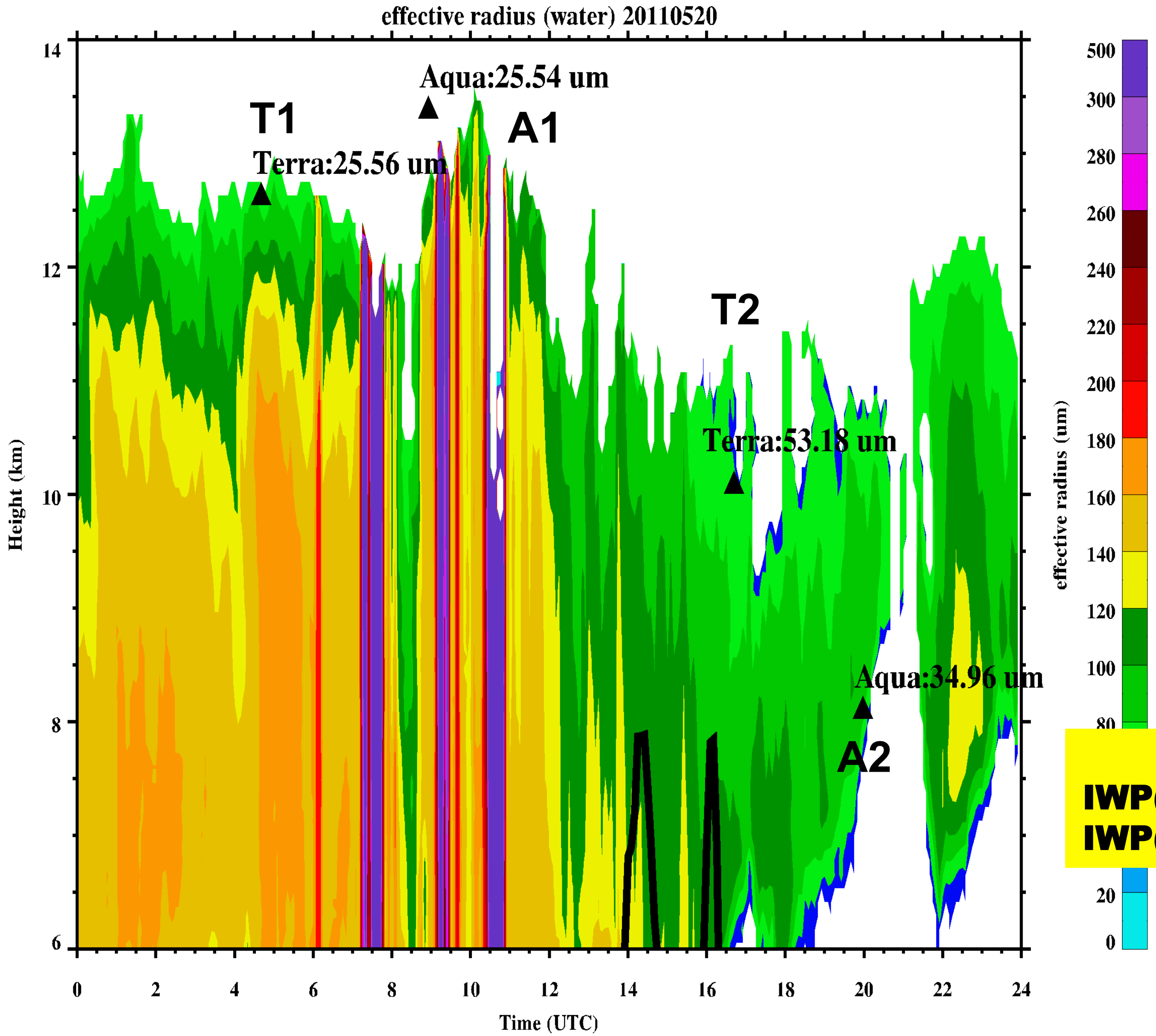


- $\Delta Z = .0025*LWP - .015*(T_{top} - T_0) + .359$
- R-value=.45

Conclusion/Future Improvements

- **Similarities between ARM sites**
  - **Linear relationship between Cloud Top temperature and Cloud Thickness**
  - **Logarithmic relationship between Liquid Water Path and Cloud Thickness**
- **Differences between ARM sites**
  - **Due to the high variability of data at the NSA the slope of the line is much smaller compared to the other sites.**
- **SGP data has better relationship for ΔZ and LWP, but not for cloud temp.**
  - **Derived seasonal relationships?**
- **Azores data has better linear correlation**
  - **Less extreme seasons**
- **Include weighting to account for instrumental error**

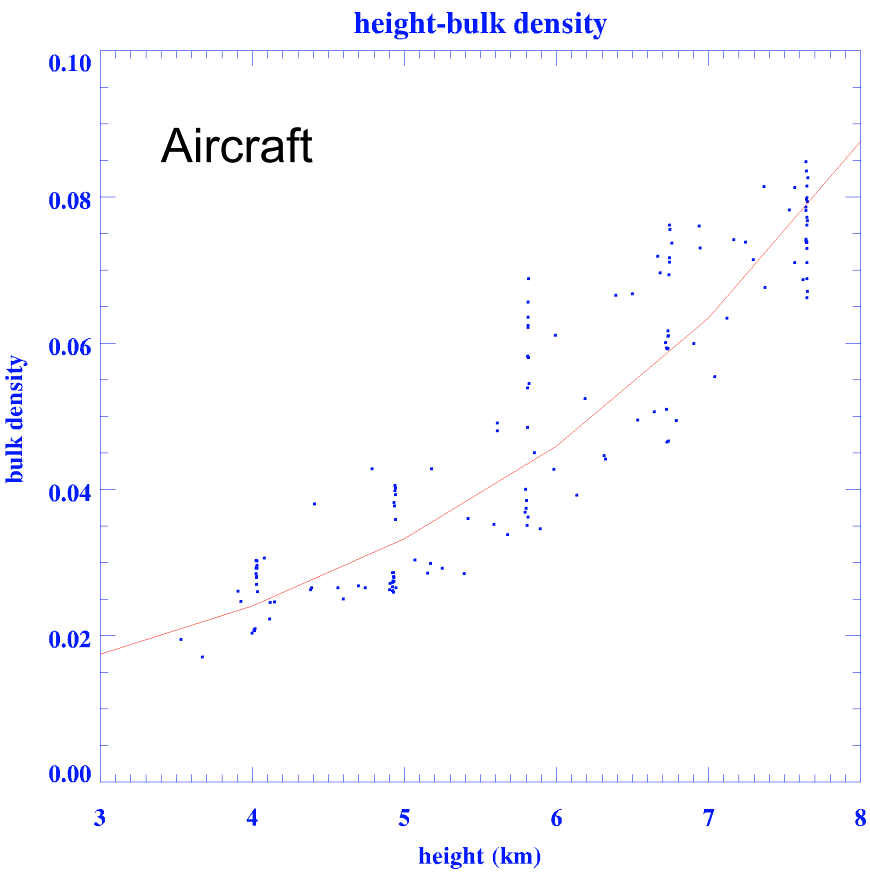
Method 1: assume ρ=1 (water)

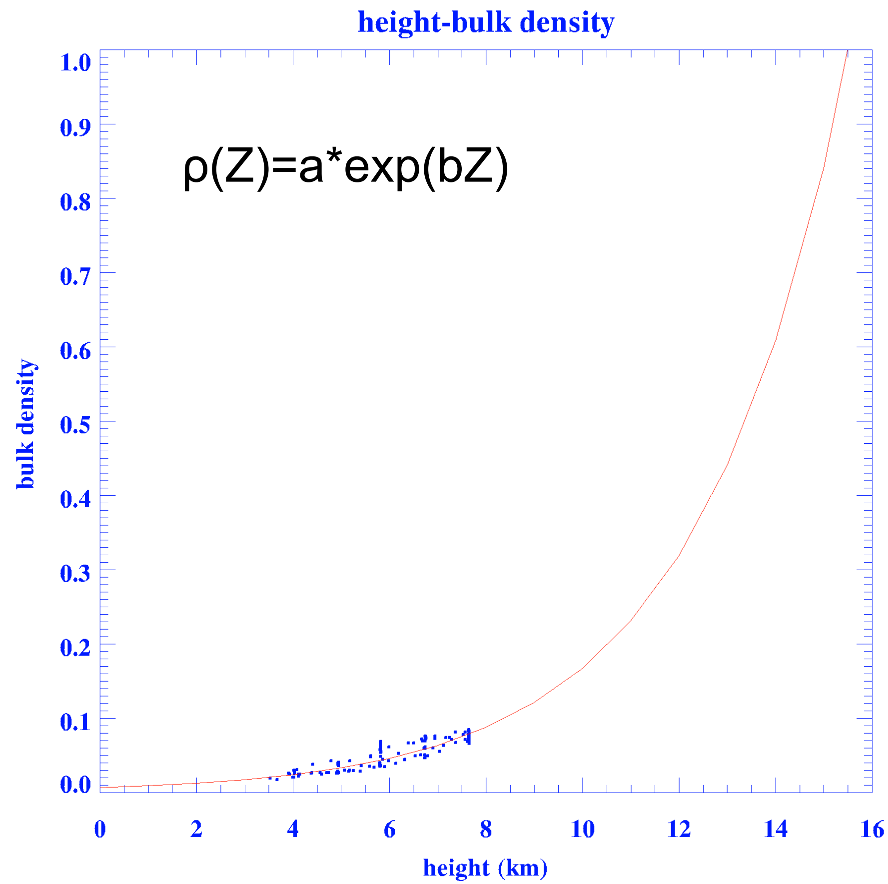


Re at T2 overpass is the most close one to our retrieval, and the other 3 are much smaller than Re retrieved by M1.

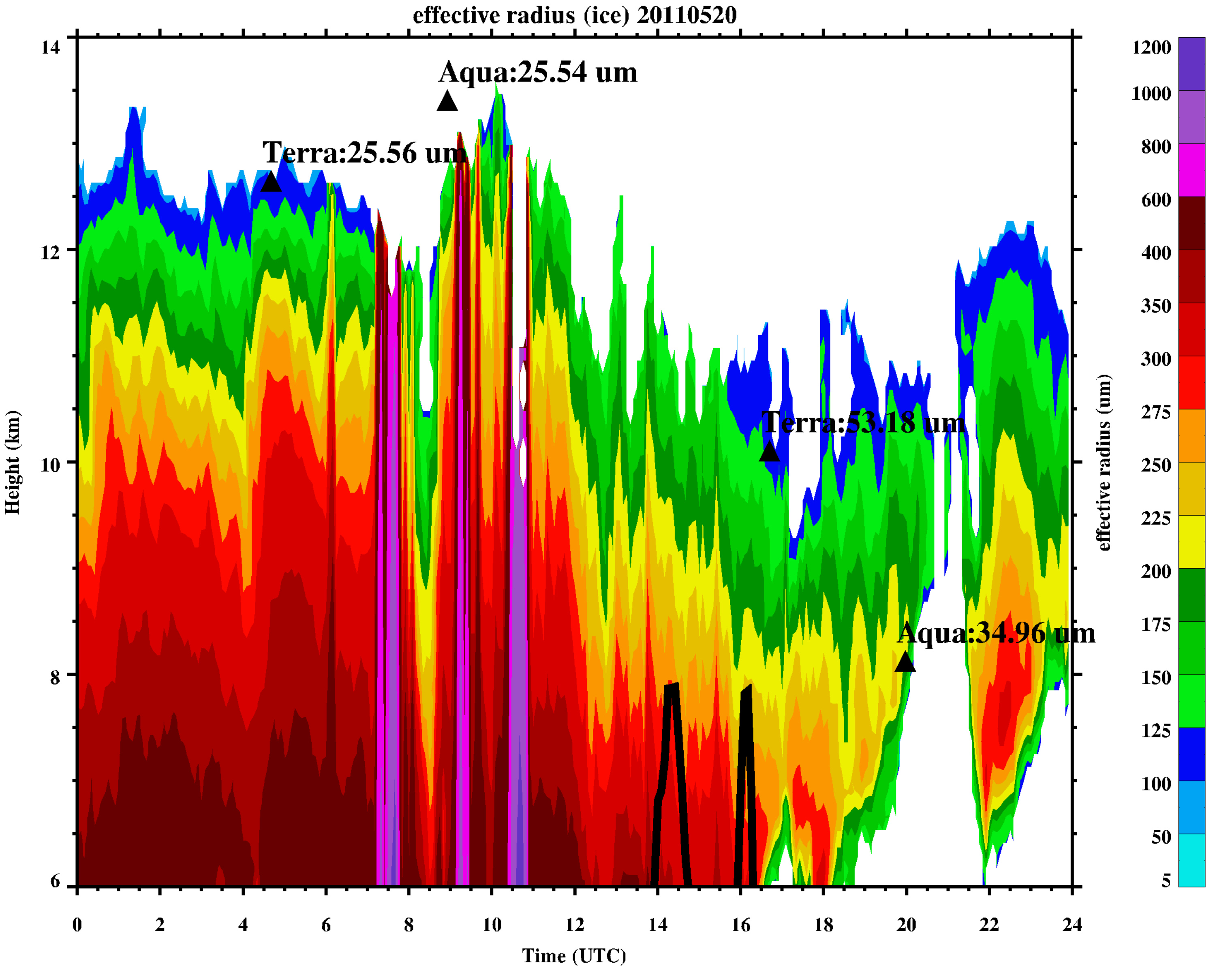
30x30km²/100x100km²
IWP(SFC) =648/1190 gm⁻²
IWP(CERES)=515 /878 gm⁻².

Bulk density: ρ

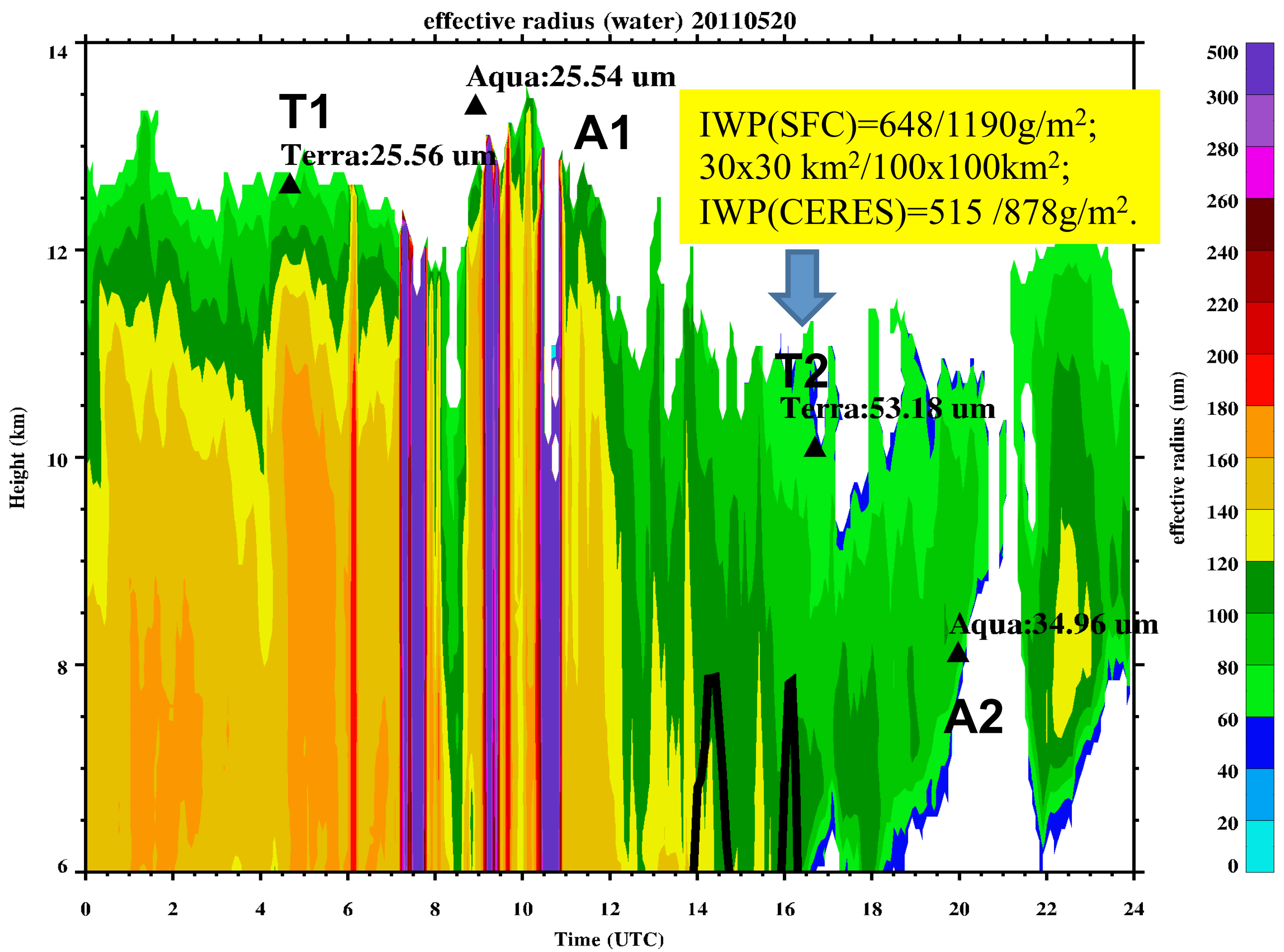




Re retrieved by Method 2: assume $\rho(Z)=a * \exp(bZ)$



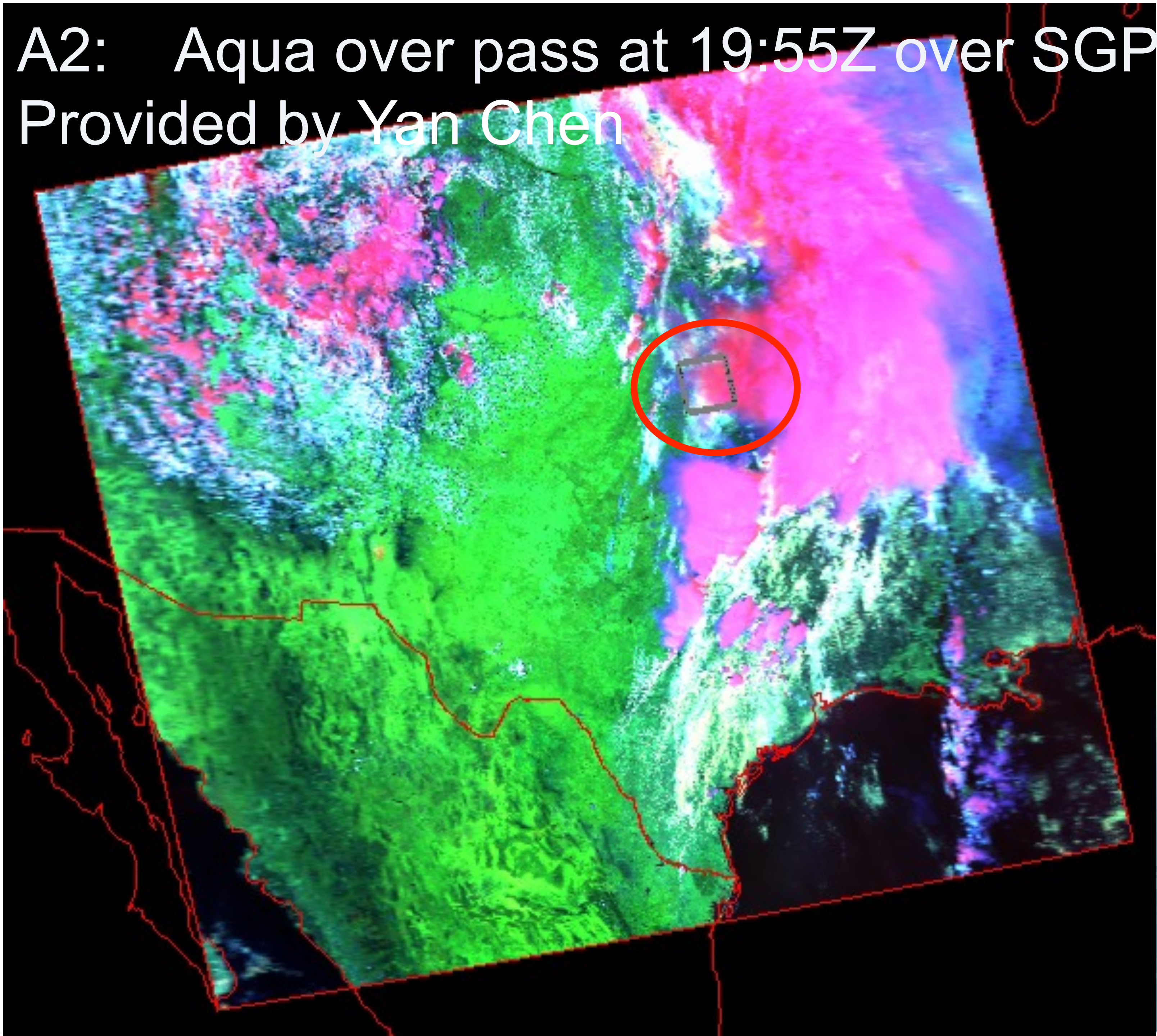
Ice Water Path

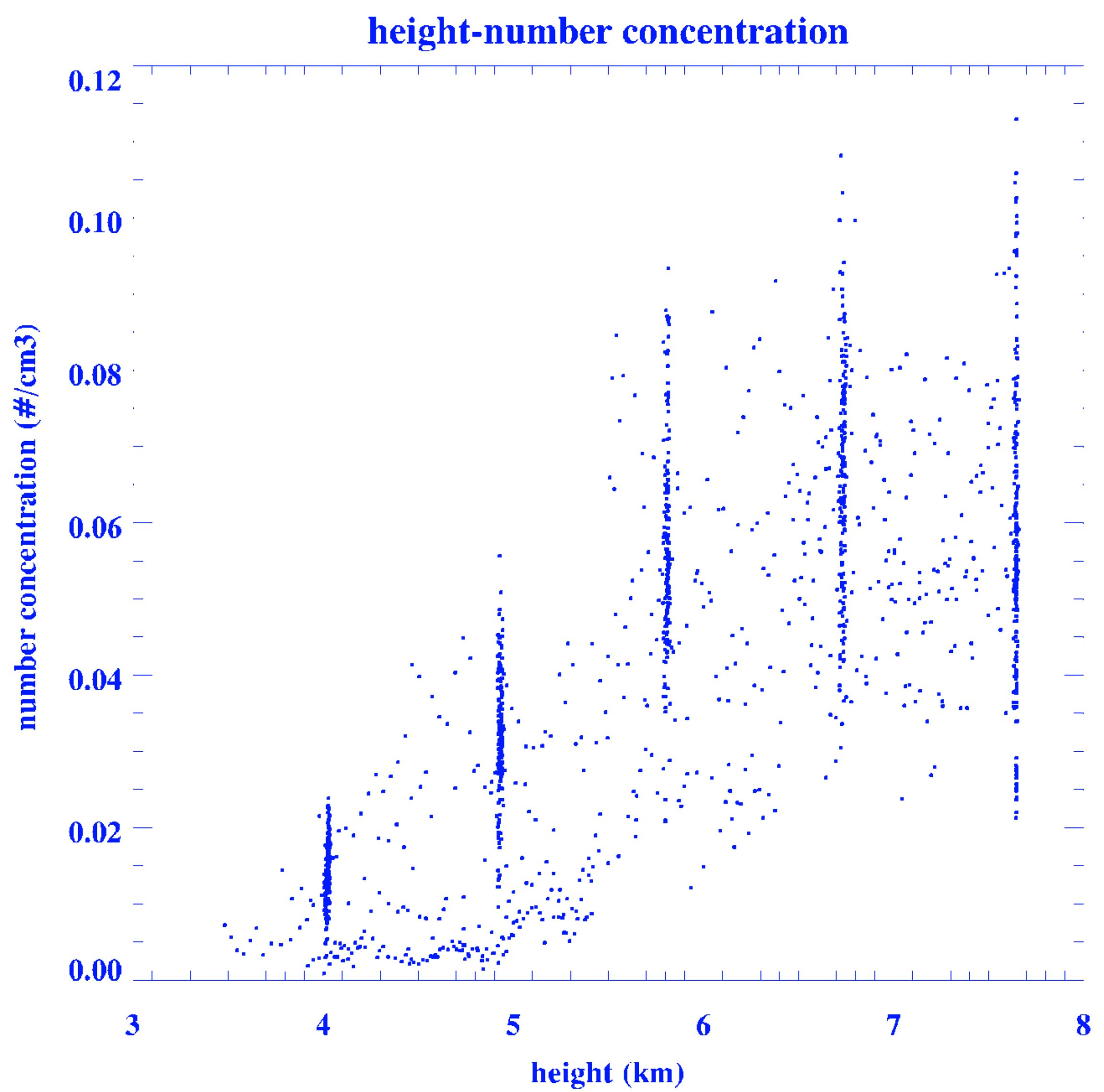


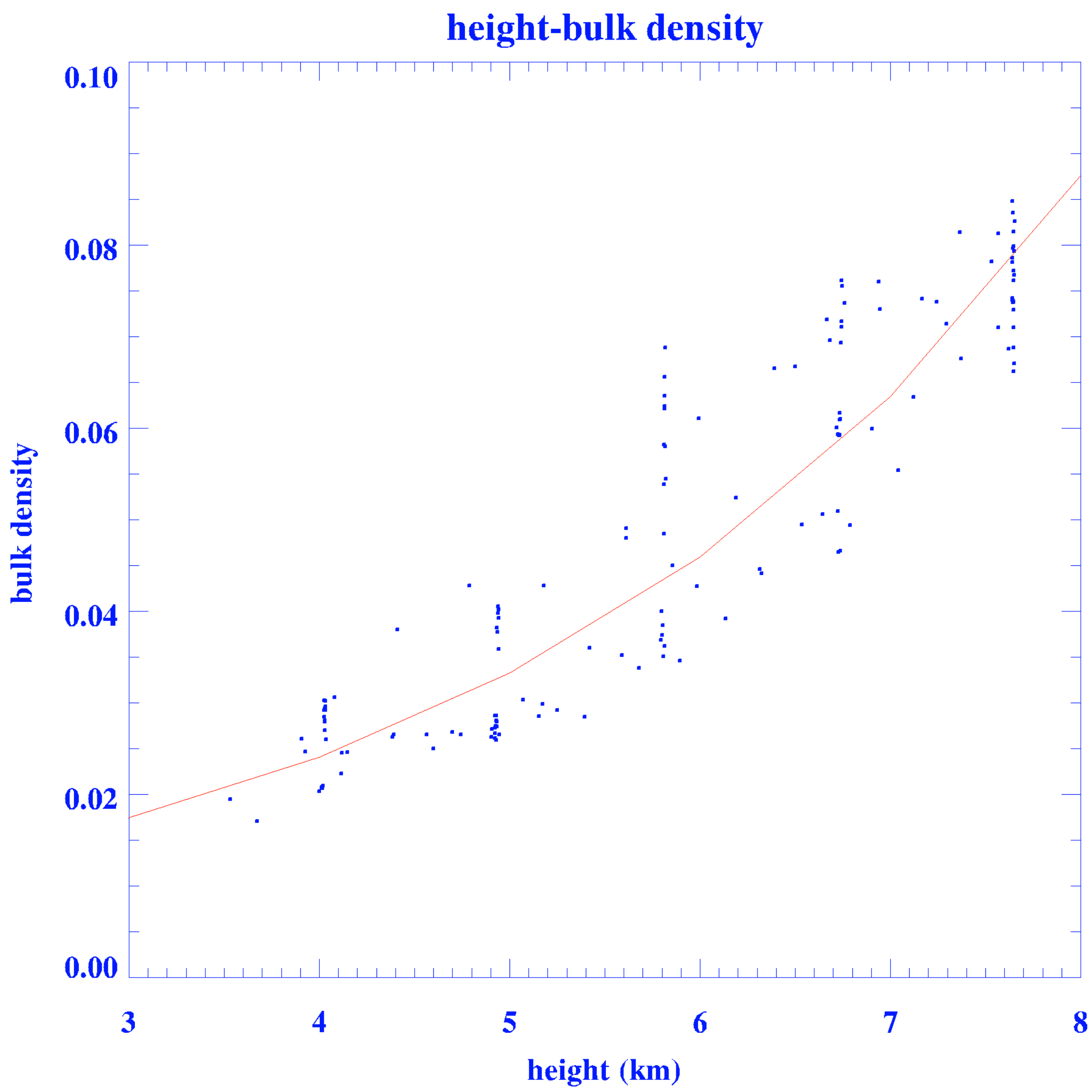
Since there is aircraft measurement (IWC) closed to T2 overpass, we compared the IWP calculated by using aircraft measured IWC and NEXRAD cloud thickness over 30x30km^2 and 100x100km^2 centered at SGP

A2: Aqua over pass at 19:55Z over SGP

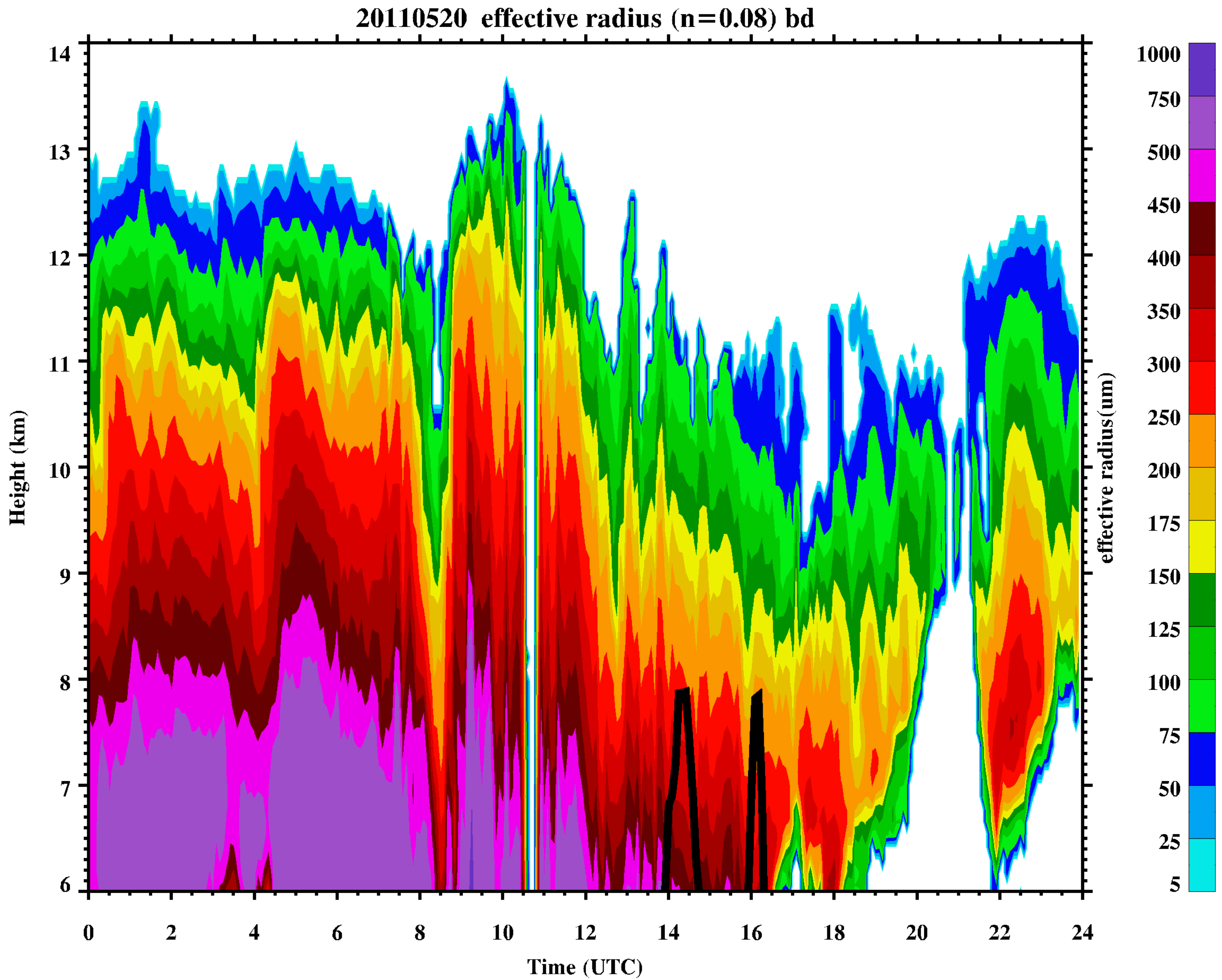
Provided by Yan Chen



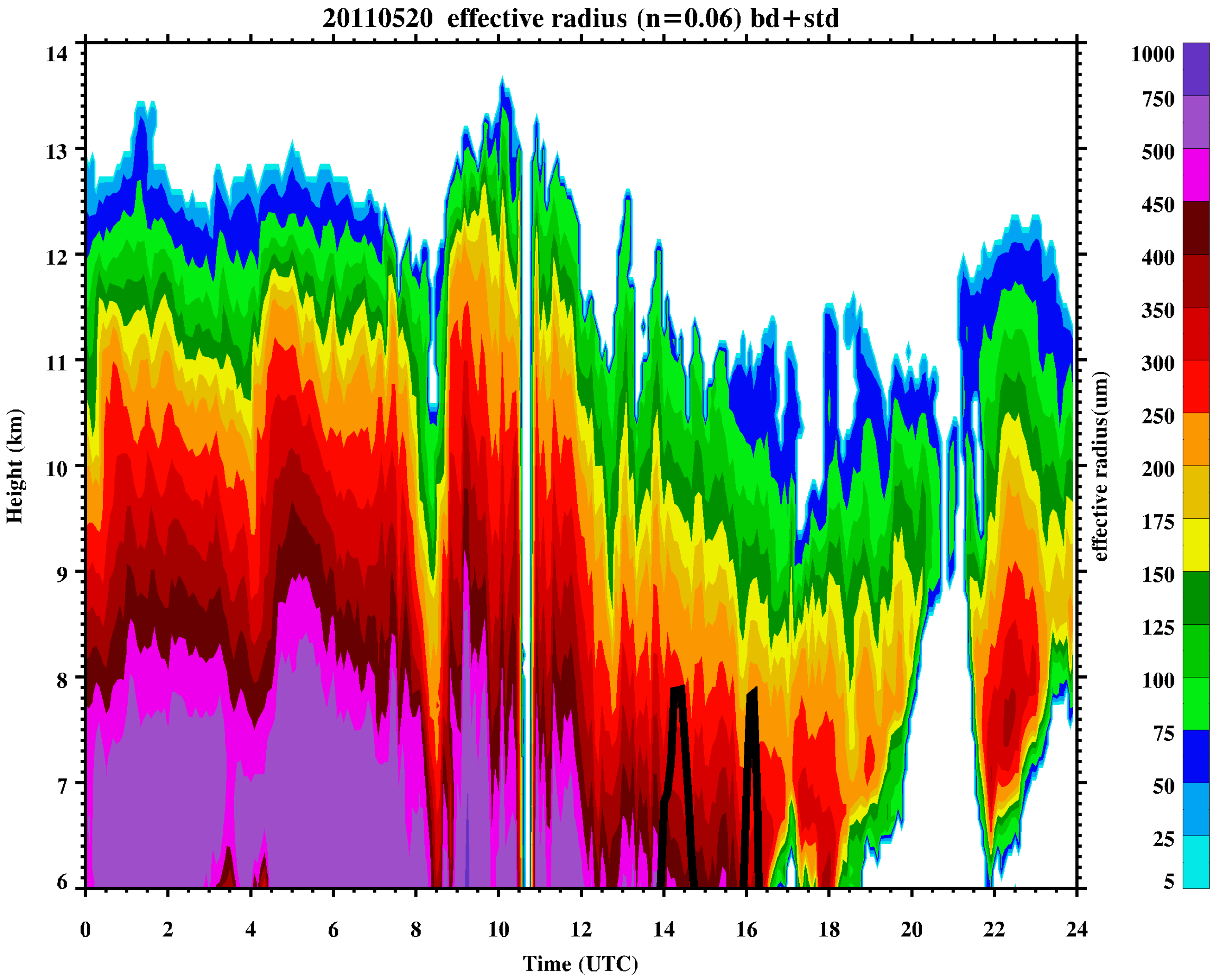

height-number concentration
number concentration (#/cm3)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
3
4
5
6
7
8
height (km)



height-bulk density
0.10
0.08
0.06
0.04
0.02
0.00
bulk density
3
4
5
6
7
8
height (km)



20110520 effective radius (n=0.08) bd
Height (km)
Time (UTC)
effective radius(um)
14
13
12
11
10
9
8
7
6
0
2
4
6
8
10
12
14
16
18
20
22
24
1000
750
500
450
400
350
300
250
200
175
150
125
100
75
50
25
5



20110520 effective radius (n=0.06) bd+std
Height (km)
14
13
12
11
10
9
8
7
6
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (UTC)
effective radius(um)
1000
750
500
450
400
350
300
250
200
175
150
125
100
75
50
25
5

Cloud droplet terminal fall speed

TABLE 8.1. *Terminal Fall Speed as a Function of Drop Size (equivalent spherical diameter) (From Gunn and Kinzer, 1949)*

Diam. (mm)	Fall speed (m/s)	Diam. (mm)	Fall speed (m/s)
0.1	0.27	2.6	7.57
0.2	0.72	2.8	7.82
0.3	1.17	3.0	8.06
0.4	1.62	3.2	8.26
0.5	2.06	3.4	8.44
0.6	2.47	3.6	8.60
0.7	2.87	3.8	8.72
0.8	3.27	4.0	8.83
0.9	3.67	4.2	8.92
1.0	4.03	4.4	8.98
1.2	4.64	4.6	9.03
1.4	5.17	4.8	9.07
1.6	5.65	5.0	9.09
1.8	6.09	5.2	9.12
2.0	6.49	5.4	9.14
2.2	6.90	5.6	9.16
2.4	7.27	5.8	9.17

1) 0< r<40 um, $V_f=K_1r^2$, Stokes' law, $K_1=1.19*10^6\ cm^{-1}\ S^{-1}$
2) 40<r<0.6 mm, $V_f=K_2r$, linear law, $K2=8*10^3\ S^{-1}$
3) 0.6<r<2 mm, $V_f=K_3r^{1/2}$, Square root law, $K_3=2.2*10^3\ (\rho/\rho 0)^{1/2}\ cm^{-1}\ S^{-1}$, ρ is air density, ρ0 is a reference density of 1.2 kg/m3. (Rogers and Yau book, P124-126)

how to get z (radar reflectivity factor)

- All the Doppler weather radars provide a measurement of equivalent radar reflectivity factor.

- use drop size distribution, particle size data

$$Z = \int_0^\infty N(D) D^6 dD$$

When particle size data are analyzed to determine radar variables, the quantity usually calculated is the radar reflectivity factor Z and not the equivalent radar reflectivity factor Ze. (Smith,1984)

equivalent radar reflectivity factor---radar reflectivity factor relationship for ice particles:

For ice particles:

(Atlas ,1995; Smith,1984;Wang 2001)

$$Z_e = \frac{|K|_i^2}{|K|_w^2} Z.$$

From KAZR

Dielectric factor: 0. 88

K_i/ρ_i is nearly constant as particle bulk density changes.

For solid ice, bulk density is about 0.92 g cm^{-3}, and $K_i^2 = 0.176$. (ATLAS, 1995)

$$\left(\frac{K_i}{\rho_i}\right)^2 \approx 0.208.$$

$$K_i^2 = 0.208 * \rho_i^2$$

Cirrus layer microphysical properties derived from surface-based millimeter radar and infrared interferometer data

Gerald G. Mace

Department of Meteorology, University of Utah, Salt Lake City

$$N(D) = N_x \exp(\alpha)\left(\frac{D}{D_x}\right)^{\alpha} \exp\left[-\frac{D\alpha}{D_x}\right] \quad (2)$$

where D_x is the modal diameter and N_x is the number of particles per unit volume per unit length at the functional maximum. Analysis of in situ data [*Dowling and Radke*, 1990] suggests that for cirrus $\alpha \leq 2$. We therefore set $\alpha=1$ and use observations to estimate D_x and N_x.

$$Z = \int_0^\infty N(D) D^6 dD$$

$$N(D) = N_x \exp(\alpha) \left(\frac{D}{D_x}\right)^\alpha \exp\left[-\frac{D\alpha}{D_x}\right]$$

$$Z = N_x e^\alpha D_x^7 \frac{(6+\alpha)!}{\alpha^{7+\alpha}}$$

$$N_T = D_x N_x e^\alpha \frac{\alpha}{\alpha^{\alpha+1}}$$

Nt is the total particle concentration

$$r_e = \frac{D_x}{2} \frac{(3+\alpha)!}{(2+\alpha)!} \alpha^\alpha$$

re is the effective spherical raius

$$Z = N_T * 2^6 * r_e^6 * \frac{(6+\alpha)!}{\alpha^{6\alpha+7} * (3+\alpha)^6} * 10^{-12} ----(mm^6/m^3)$$